Exploring the Utility of Sponge Cities and Rhs for Rainwater Utilization and Urban Flood Prevention

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Abstract. The problems of water scarcity and urban waterlogging have a serious impact on people's lives and social development. The frequency of extreme weather events exacerbates this phenomenon. The new concept of sponge cities and Rainwater Harvesting Systems (RHS) came into the picture. Sponge cities and RHS are important for mitigating this phenomenon, especially in terms of rainwater utilization. This paper reviews the literature on sponge cities and RHS and analyses the position and effectiveness of both in solving the problem of waterlogging and improving the efficiency of water resources. The research found that both sponge cities and RHS can effectively improve the utilization of water resources. Sponge cities can decrease surface runoff and decrease the emerging risk of extreme weather. The purpose of this paper is to discuss the future development of sustainable drainage storage systems and to review past developments that can inform scholars of drainage storage in the context of sustainable development.

Keywords: Sponge City, Rainwater harvesting, sustainable development.

1. Introduction

In nowadays' world, the shortage of water resources is still a big problem. The United Nations proposed Sustainable Development Goals for 2030 in 2015 which include access to clean water (Goal 6) and sustainable cities and communities (Goal 11) [1]. The growth of global populations, irrigation as well as the needs for economic development all aggravate the overuse of water. The phenomenon of deterioration of river water, decreasing river flow, and depletions of groundwater all indicate that humans have already overused water resources unsustainably [2]. Previous research has shown that from 2010 to 2050, global household water demand will grow up to 300% [3]. Improving the proportion of water utilization is the top priority. To meet these water scarcity challenges, rainwater harvesting systems (RHS) emerge as a potential solution that can help achieve sustainable development goals.

At the same time, more and more extreme weather is attacking people's lives. Extreme rainstorms and floods become more frequent. While extreme precipitation brings waterlogging problems to cities, it also brings a large amount of freshwater that can be utilized by people. Despite extreme weather events bringing challenges, as a strategic tool, the Rainwater Harvesting System (RHS) can solve the problems of city waterlogging issues by effectively utilizing the abundant fresh water produced during extreme weather events.

In previous research and studies, RHS was proven to mitigate the impact of urbanization, by harvesting rainwater, RHS can reduce surface runoff and cut down peak flow, so it can utilize the natural hydrological loop of urban areas and decrease the risk of flood [1]. It can also cut down the energy consumption of rural areas indirectly by replacing the drinking water with harvested rainwater [1]. However, rainwater is still underestimated in water resource management systems [4,5]. RHS can bring household economic benefits due to lower water management and treating costs as well as reduced non-point source pollution [5]. Much research on RHS remains static, but many countries have started to consider RHS as a viable decentralized water source and utilize it to meet their own sustainable goals.[3,5]. The research of Yannopoulos et al. reveals that RHS can be put to good use in rural areas [5].

In China, the newest research and implementation of RHS are the construction of 'Sponge City'. A multitude of developed areas have experimented with the sponge city concepts and had some beneficial effects. The main components of Sponge City are grassed swales, Eco Green Roofs (EGR), rain gardens, sunken green spaces and permeable roads [6].

Based on the above background and research status, this paper can give readers a basic understanding of rainwater harvesting, especially sponge cities. This paper will focus on the current application of sponge cities, the feasibility of preventing city waterlogging by using sponge cities, and prospects for rainwater utilization, and give some suggestions.

2. Current Applications and Constructions of Sponge Cities

2.1. Sustainable Drainage Concepts in the World

In a traditional drainage system, the pipes and pump stations mainly take the responsibility of collect and transferring rainwater which is called grey drainage system due to the color of the concrete. During the grey drainage was heavily built in each city, the building concept of a green drainage system gradually entered the public's eyesight. The common green drainage systems that have been widely built are LID in the United States, BMPs, Green Infrastructure and GSI, the Sustainable Drainage System (SUDS) in the United Kingdom, the Storm Water Harvesting system and Storm Water Management system in Germany, the WSUD in Australia, the LLUDD in New Zealand [7]. These green drainage systems all adhere to the green and environmentally friendly low-impact development concept, sustainable as well, catering to the general background of sustainable development.

In this kind of global development trend, China put forward its own idea. "Comprehensively build a green, resilient, and smart modern urban drainage and flood prevention engineering system", this is an object of the Chinese government until 2035.

Sponge cities, as one of the important measures of solving the waterlogging problems, were proposed by Chinese government [8]. The nature of a sponge city is making the rainwater more natural in cities' water cycle, changing the rainwater management mode that grey drainage dominate the drainage system, following nature and improving rainwater's penetration, storage, purification, utilization and discharge capabilities [7].

2.2. Chinese Investment and the Effect of Sponge City

In 2015, first batch of 16 experimental cities of Sponge City was determined. The second batch of 14 counterparts were determined too in 2016. The investment in sponge city construction is between 27 billion and 210 billion yuan, about 1 to 1.1 billion yuan per square kilometer, and an average of 320 million yuan per square kilometer.

Many people and experts felt very confident in the effect of Sponge City because people always think that high investments can bring high returns. But the truths were always the most convincing. Despite high investment, in 2016, shortly after only two batches of experimental cities began building sponge cities, according to data, 19 of the 30 experimental cities encountered waterlogging problems after the south of China entered the flood season [7]. The effect of Sponge City was not as good as people thought. This situation caused a lot of discussion, some experts thought that sponge cities, as green infrastructure, have drawbacks like low efficiencies, and high area occupancy rate despite of advantage of low investment and maintenance costs [7]. Actually, sponge city does not have a very great effect on preventing extreme waterlogging, by contrast, it is only good at controlling small or medium rainfall peak flow and "absorb" the rainwater, then "squeezing the water out" when people need to utilize the rainwater, this is the position of sponge city in preventing waterlogging and increasing rainwater utilization rate.

2.3. The Main Compositions of Sponge City

Firstly, one of the main compositions of Sponge City is grassed swales, it has similar effects with EGR, the only difference is that it is applied on the side of road but not rooftop. Which are usually built with grass swales together is permeable road, which can intercept rainwater effectively as well as decrease the contaminants [6]. Next one is EGR. EGR beautifies the city and also plays a role in intercepting rainwater. According to the research of Seping Dai et al., when the thickness of the matrix are 30mm, 50mm and 70mm, rainwater interception rate can be 23.29%, 27.20% and 28.44 respectively [6]. Sunken green space is also an important composition of Sponge City, it has a good runoff reduction rate from 23.14% to 67.04% and a better harvesting function, it needs lower investment compared to EGR [9]. Finally, there is Rain Garden. A rain garden is common in Japan, there are two typical rain gardens in the University of Kyoto Uzumasa Campus, the overall area are 409.25m2, from the monitoring data of Linying Zhang, these two garden both have good water storage and infiltration effects which can control extreme rainfall runoff up to 60% [6]. According to the study of Shuangcheng Tang et al., a rain garden in Xian (a city in Shanxi Province, China) had steady infiltration rate and the extreme rainfall runoff reduction rate was up to 99.0% in the first 4 years of implementation [10].

2.4. A Simulation of A Research Area

For the whole sponge cities' effect, Ming Tang et al. make a simulation. They chose a research area in Nanchang municipality, the research area is a common community in Honggutan District. The area has complete and mature traditional grey drainage system and a newly built Sponge City. The area image is given in Fig.1. Ming Tang et al. use the Mike rainfall model to generate a virtual Chicago rain pattern rainfall in this research area, and then they get the simulation results.

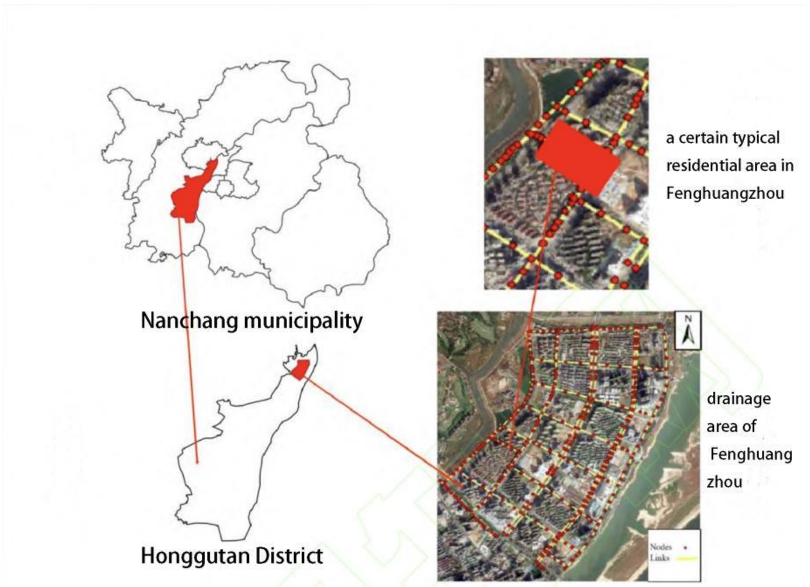

Fig 1. The research area map [7]

The simulation results are shown on the figure given below. As Fig. 2 indicates, with the return period raise, total external emission reduction rates do not differ in a large extent as the peak flow reduction rate do, maintained at 23%~29%, but the peak flow reduction rate decreases from 28% to 4%~8% which reveal that LID facilities including Sponge City can only have little effect to extreme rainfall. Although Sponge City can not prevent extreme waterlogging problems like people imagine, it can assist traditional drainage systems, and alleviate the waterlogging problems.

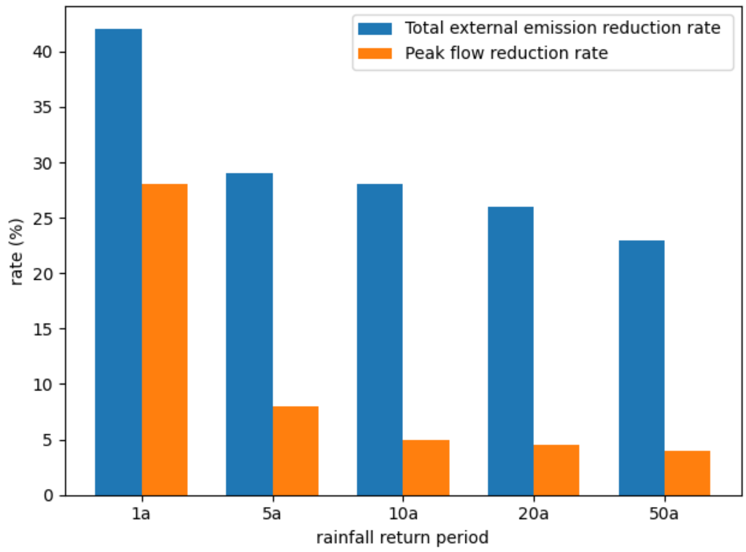

Fig 2. The peak flow control effect before and after LID construction [7]

3. The Application Status of RSH

The Sponge City is a concept of urban sustainable development, as one of the key technologies of Sponge City, RHS plays an important role in achieving rainwater management and sustainable utilization of water resources. In Sponge City, rainwater can be absorbed by the city and the city can discharge water when people need water. RHS is the main container that taking this responsibility. When the water is absorbed by the ground, it will flow to the RHS and be stored, then RHS release the water at a specific time.

The concept of RHS is not actually new, there is many archaeological evidences proving that there were big amounts of ancient RHS-liked technologies used by ancient people [3]. There are devices with simple filtering functions in Mayan ruins that can prove the ancient rainwater utilization by Mayan. In 1930s, rainwater was considered the cleanest natural water that is drinkable by some experts [3]. With the development of society, the quality of natural water resources is declining as people's lives improve. More and more contaminants enter the natural water resources including rainwater, rainwater is no longer drinkable. Then people started to think about utilizing rainwater in other wider ways, usually domestic use.

At the same time, it is also in order to meet the needs of sustainable development, RHS back into people's eyesight again, this kind of frequent technology which was common in ancient times but became less used in modern times is used more frequently in nowadays society, applied with sustainable concepts. The rainwater harvested by RHS is usually for domestic use. It can be divided into two usages, indoor and outdoor. For indoor usage, it can be potable only if rainwater is treated by filtration and some chemical ways, but it is impossible in common houses so rainwater can only be used for washing or toilet flushing. For outdoor usage, rainwater can be used for wetting the lawn or gardening. It can help us reduce lots of fresh water needs from water treatment factories.

There are many social benefits that RHS can bring. A big-scale RHS can be a part of a grey or green drainage system. Some artificial lakes in park are one kind of big-scale RHS, it not only reduce the surface flow in rainfall and decreases the risk of waterlogging but also beautifies cities, this kind of rainwater managing mode is mostly used in Singapore. During peak water use periods, the rainwater collected in the lakes can be pumped out to the building, and even when there are emergencies such as fire alarms, the water can be used to put out fires. This kind of green RHS has attracted more attention in recent years. Besides, RHS can reduce freshwater production costs, reduce contamination of ground and surface water, control heavy rainfall in flood-prone areas[11]. What is more important, if RHS is included in wide community development projects, it can provide many jobs for people as well as solve employment problems [3].

4. Suggestion

Based on the above researches, this paper can provide some suggestions for the construction of sponge cities and RHS in the future. First, although the green drainage system is not as effective as the traditional grey drainage system in preventing waterlogging, it has an excellent overall effect such as reducing a certain amount of surface runoff while beautifying the environment. It can also be combined with the RHS technology to increase the utilization rate of rainwater which can alleviate the current problem of insufficient freshwater resources to some extent. Green urban drainage systems can also reduce carbon emissions, thereby reducing the likelihood of extreme weather events and indirectly reducing the problem of urban flooding caused by extreme rainfall.

In addition, as the construction of green drainage systems and RHS such as sponge cities requires a lot of labour and investment, the government can also solve the problem of employment rate by providing a large number of jobs through the construction of these facilities. The RHS is proposed to be divided into zones, with a community having a central RHS and a decentralized domestic RHS, which can provide a portion of freshwater for daily life. The domestic RHS can provide some of fresh water for daily use. The water from the central RHS can be delivered to individual households through a network of pipes when it is close to overflowing its capacity, and the rest of the time the rainwater in it can be stored and used at times of peak water demand or in emergencies such as fires. The central RHS can be built in the form of a lake park, like the one in Singapore.

5. Conclusion

This paper introduces sponge cities and RHS from the current concerns of urban flooding and water scarcity and then summarizes the current development of sponge cities and the effectiveness of sponge cities by reviewing the literature on the subject, as well as the content of RHS. The findings of the study are summarized and recommendations are made for the future development of Sponge Cities and RHS.

Sponge Cities, as a green drainage concept under the Low Impact Development system, can directly and effectively reduce runoff and indirectly reduce carbon emissions to reduce the occurrence of extreme rainfall events and thus reduce the risk of urban flooding. However, sponge cities have limited capacity to control large, rapid runoff caused by extreme rainfall. To address this, they should be closely integrated with traditional grey drainage systems to mitigate urban waterlogging. The RHS, as an integral part of both traditional forms of grey drainage and the new green drainage, can regulate the peaks of flooding and make use of the rainwater it collects. Sponge cities and RHS can fulfill the above functions while beautifying the natural environment, and can even provide jobs to solve the employment problem through the construction of these facilities. In conclusion, Sponge Cities and RHS facilities align with the principles of sustainable development, contributing to the 2030 Sustainable Development Goals set by the United Nations.

The concept of Sponge City and RHS can bring a lot of convenience to people's lives and solve many existing problems related to water resources. In the future, the research on Sponge City and RHS can be further combined. RHS can be used in green drainage systems to integrate with the whole city to achieve sustainable development. Drainage systems around the world are continuously moving towards LID systems, so the LID of RHS should be implemented as soon as possible.

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